DESIGN AND CONTROL OF DYNAMIC TESTING SYSTEMS

Organised by

Institution of MECHANICAL ENGINEERS

Overview

Prof Andrew Plummer

University of Bath

Mechatronics, Informatics and Control Group

Seminar

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Copthorne Tara Hotel, London

The dynamic testing of structures, components and materials in the laboratory to determine their mechanical properties is an essential part of engineering R&D.

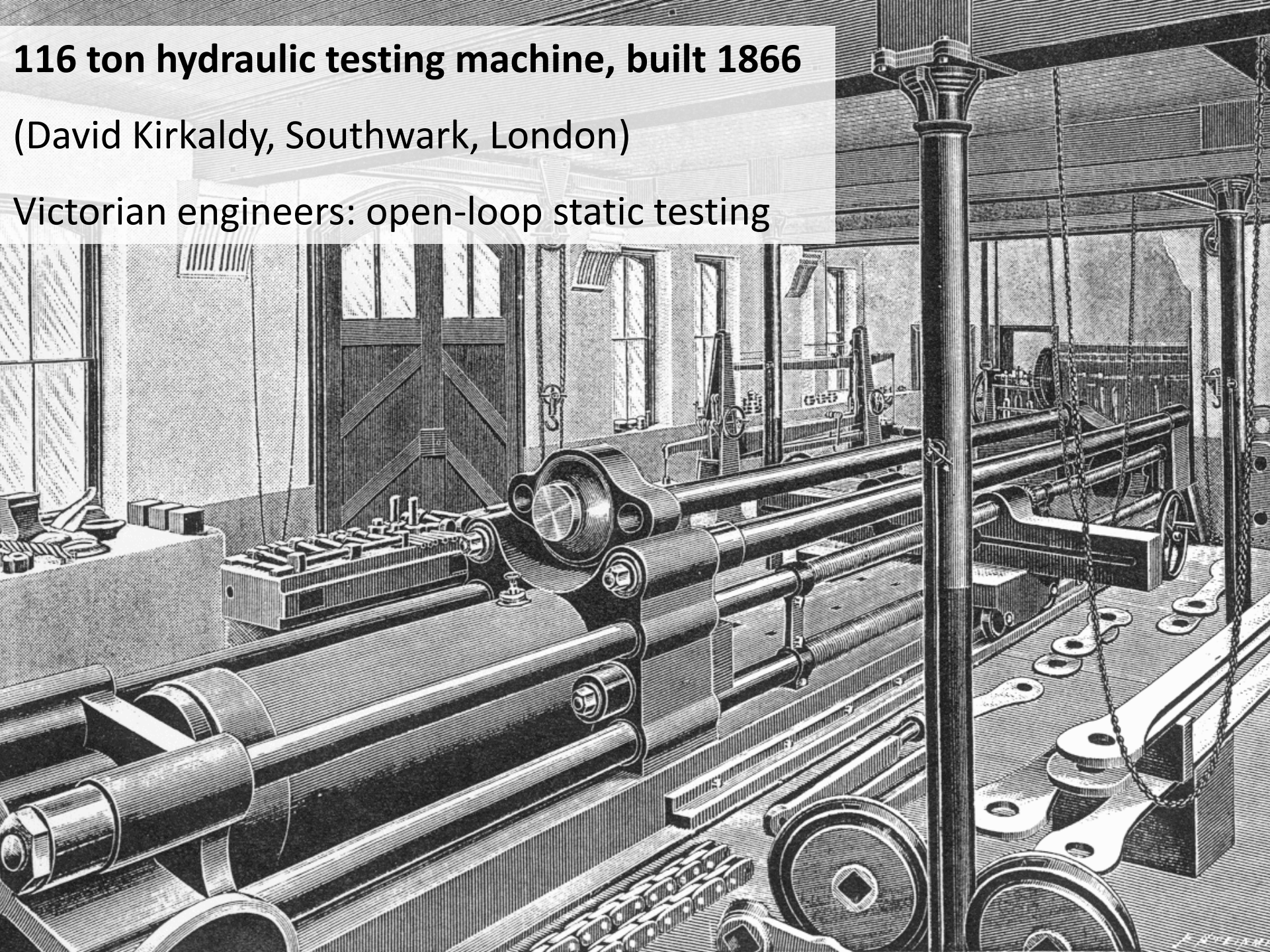
Overview

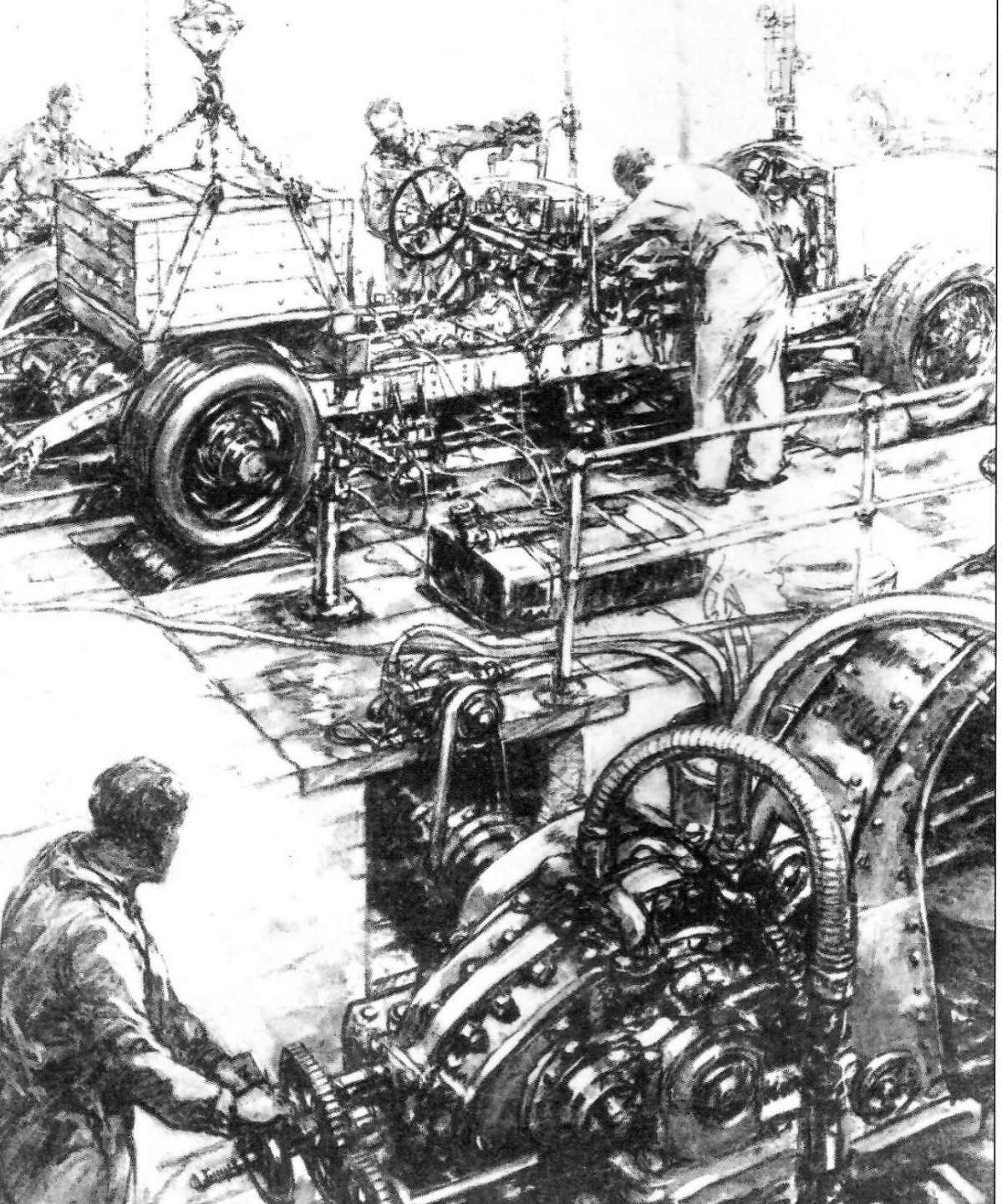
- History
- Examples – automotive, seismic …..
- Model-based design and control
- Control
- Technology

116 ton hydraulic testing machine, built 1866

(David Kirkaldy, Southwark, London)

Victorian engineers: open-loop static testing





Dynamic bump-test, 1911

Rolls-Royce, Derby

Ten years in one day

"Royce took two great drums armed with cams, mounted them on an axle, with the top of the drums level with the floor, designed a motor to rotate the drums, and all facilities for executing the destructive tests and recording them."

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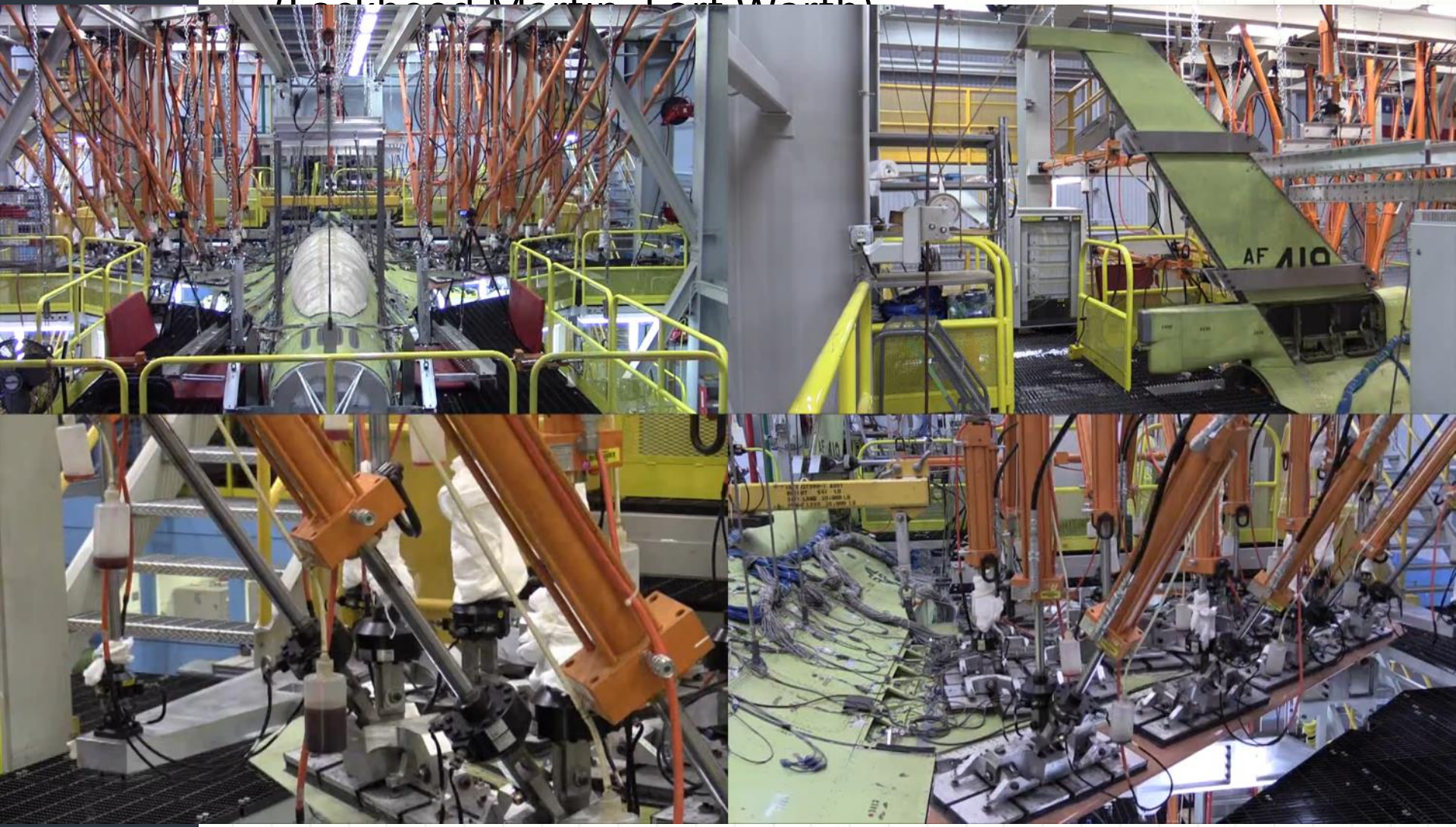
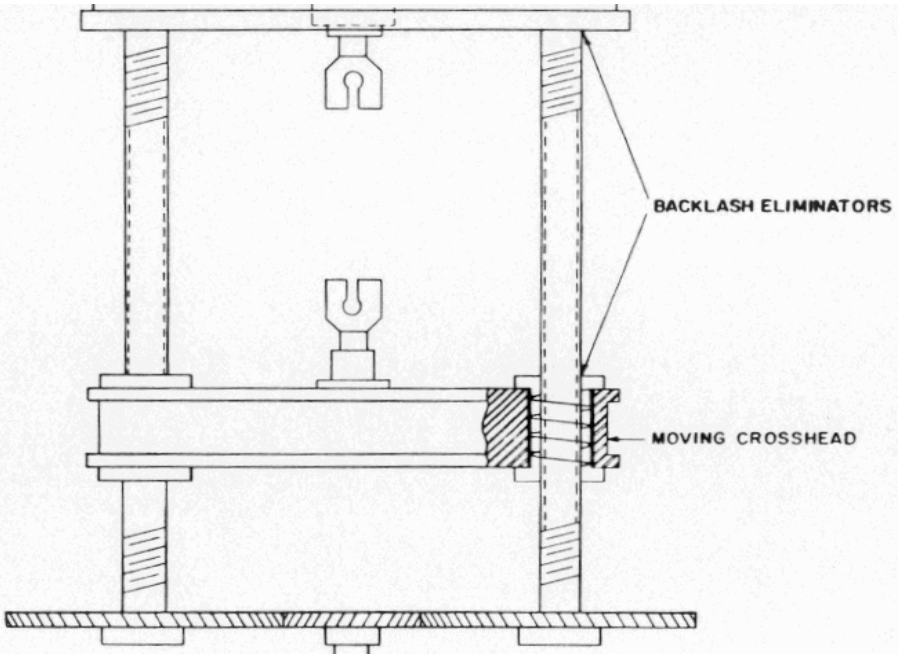
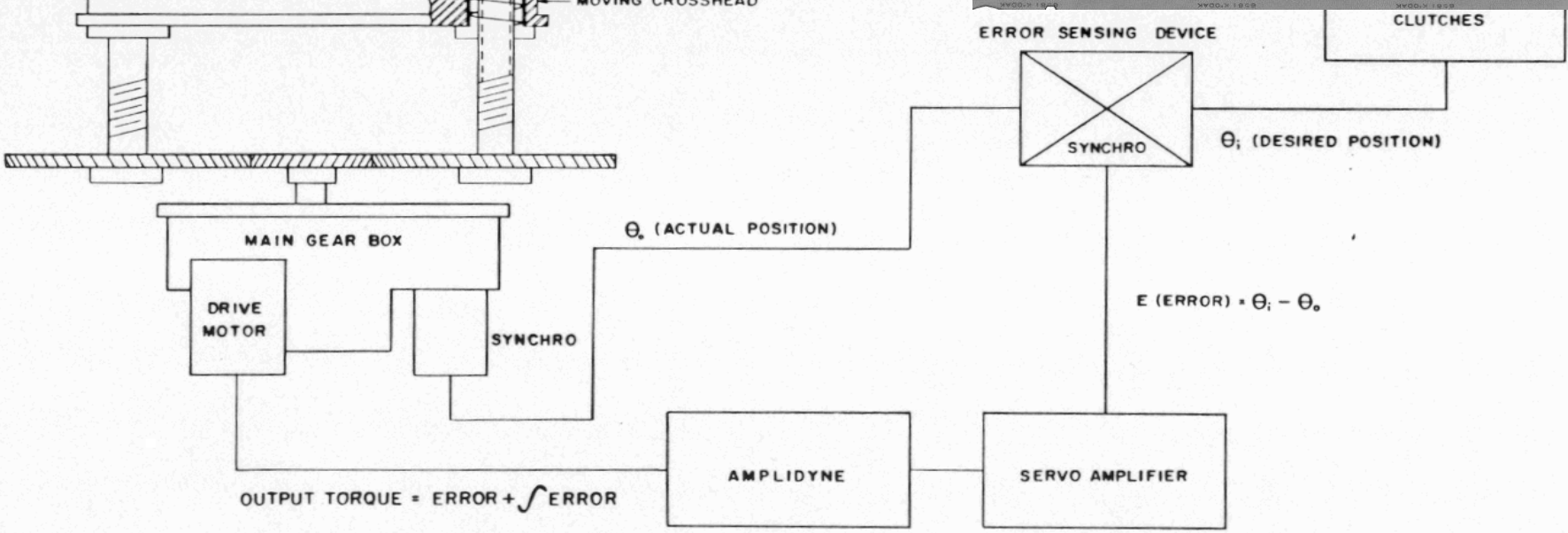
F-16 Durability Testing: 25,000 Hours, 2015

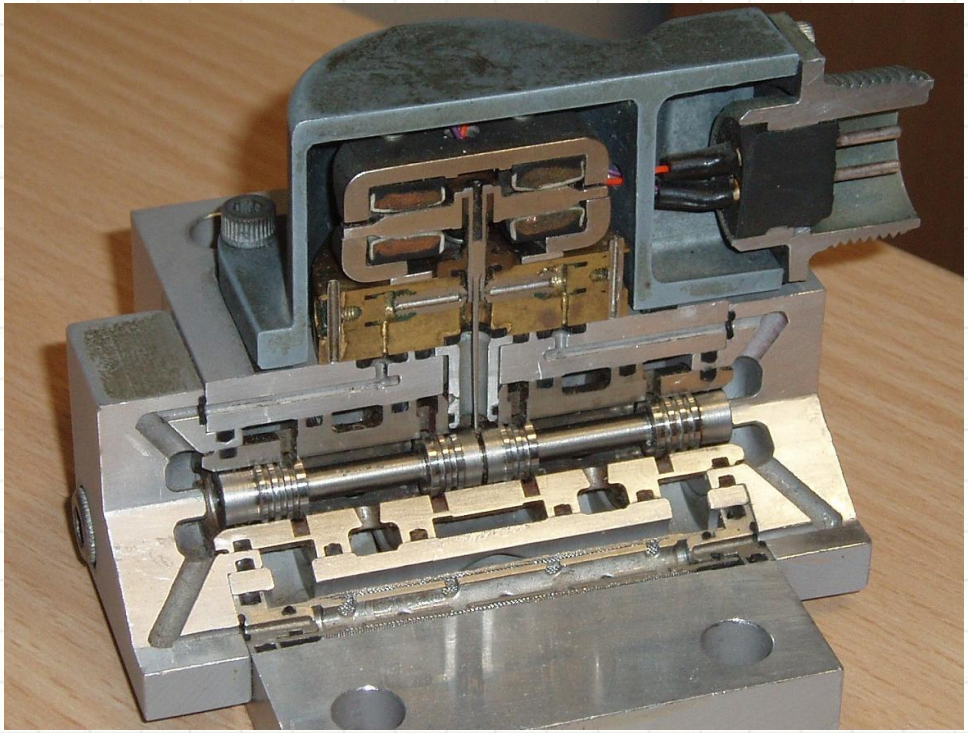


Instron 5000lbf closed loop testing machine – 1946





- Other developments
  - Servovalve developed by MIT/Moog (USA) ~1950
  - Dowty, were first in Europe (60s) with a servohydraulic materials testing machine
  - Fully digital controllers from 1980's



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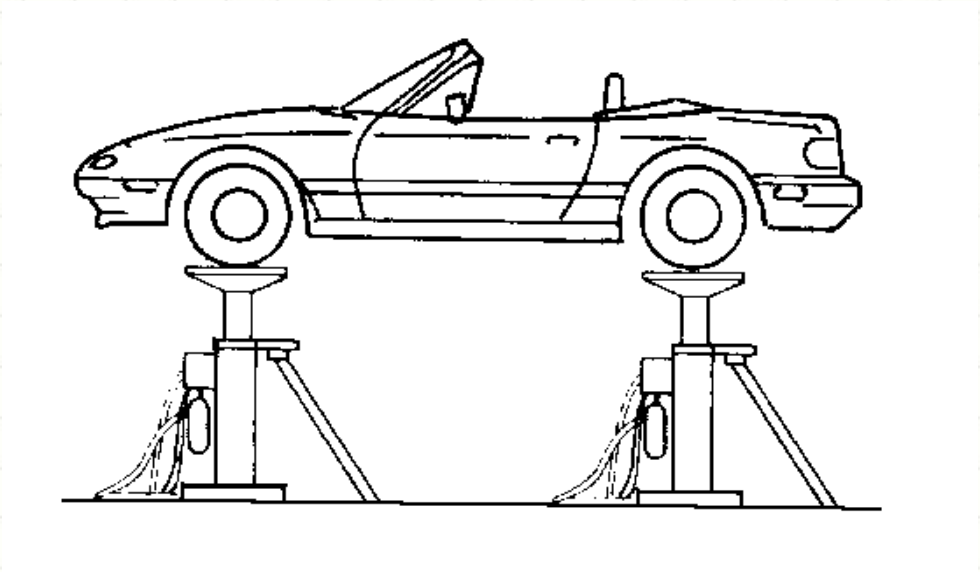
CHASSIS DURABILITY AND DYNAMICS TESTING



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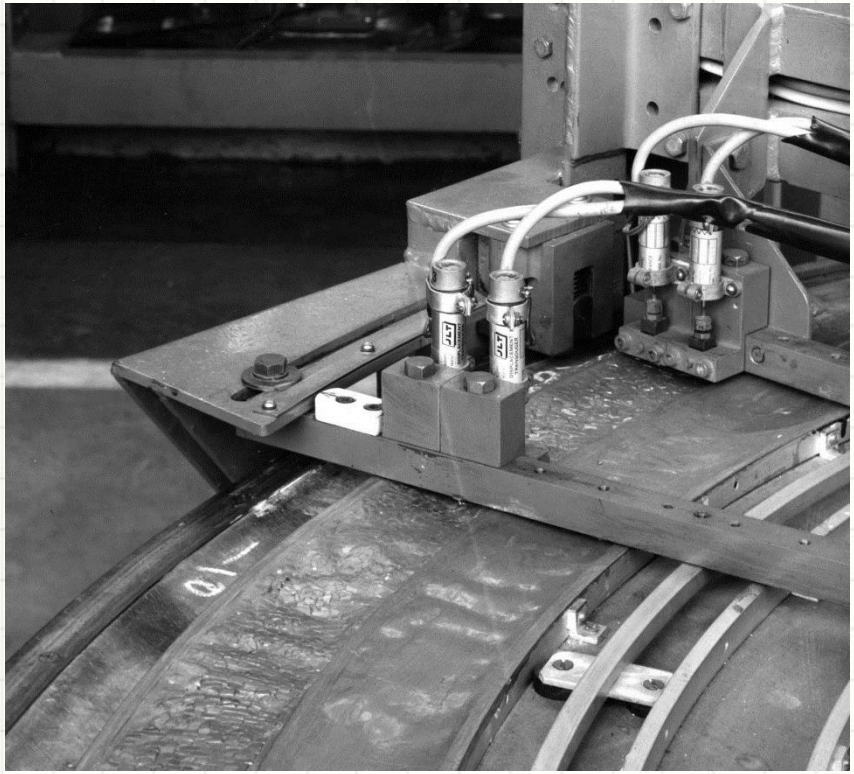
The 1960's



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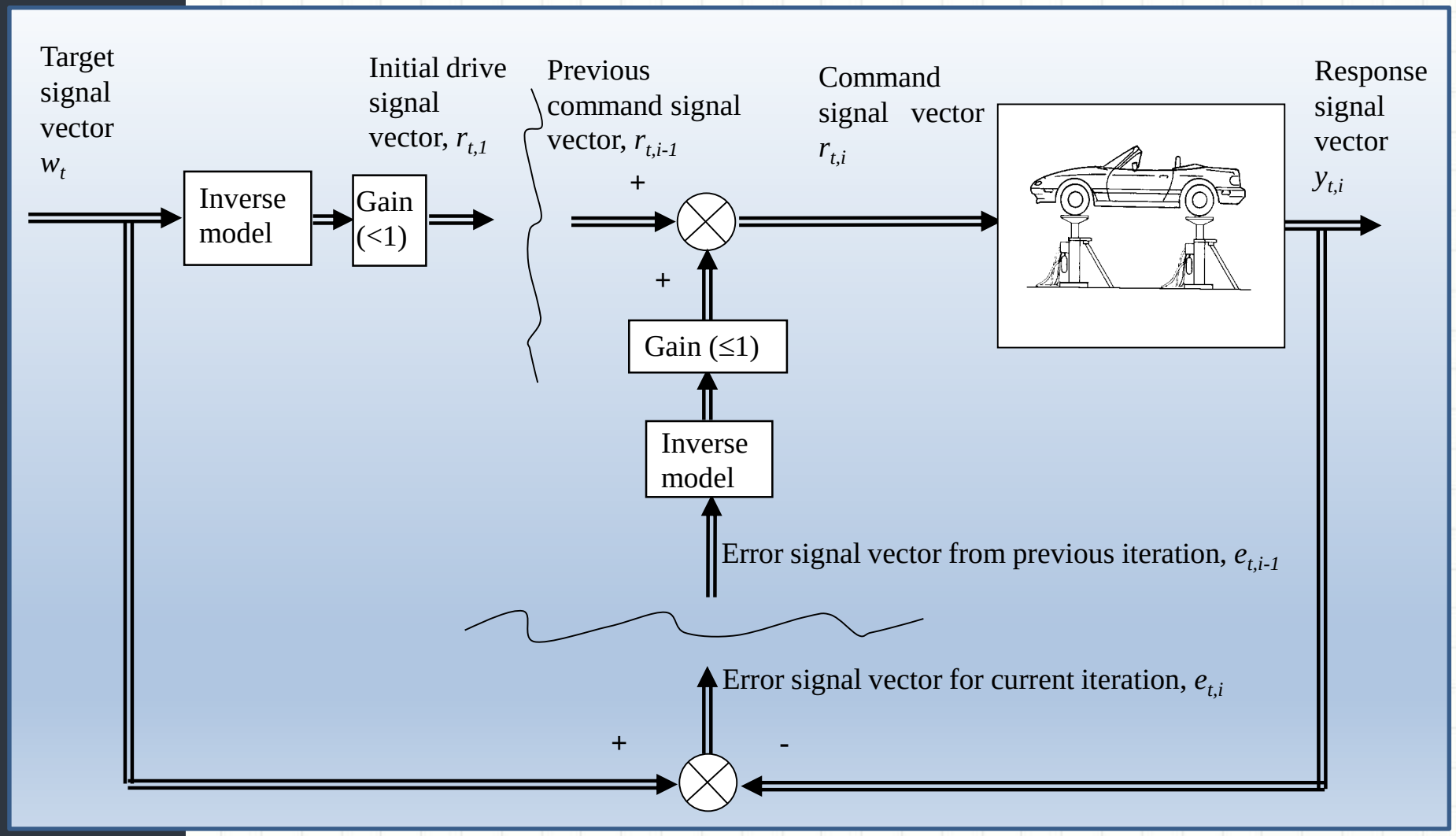
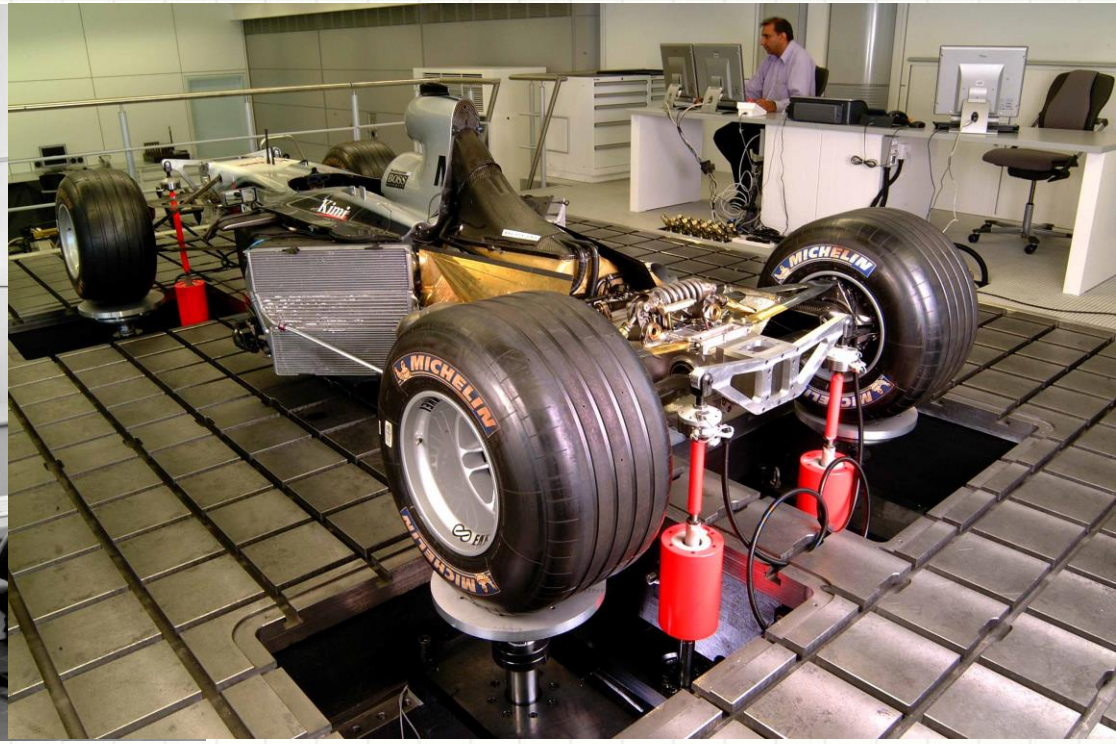
Wide range of vehicles…

Iterative Control – from the 1970's



F1 chassis dynamics testing

4 and 7/8 post rigs



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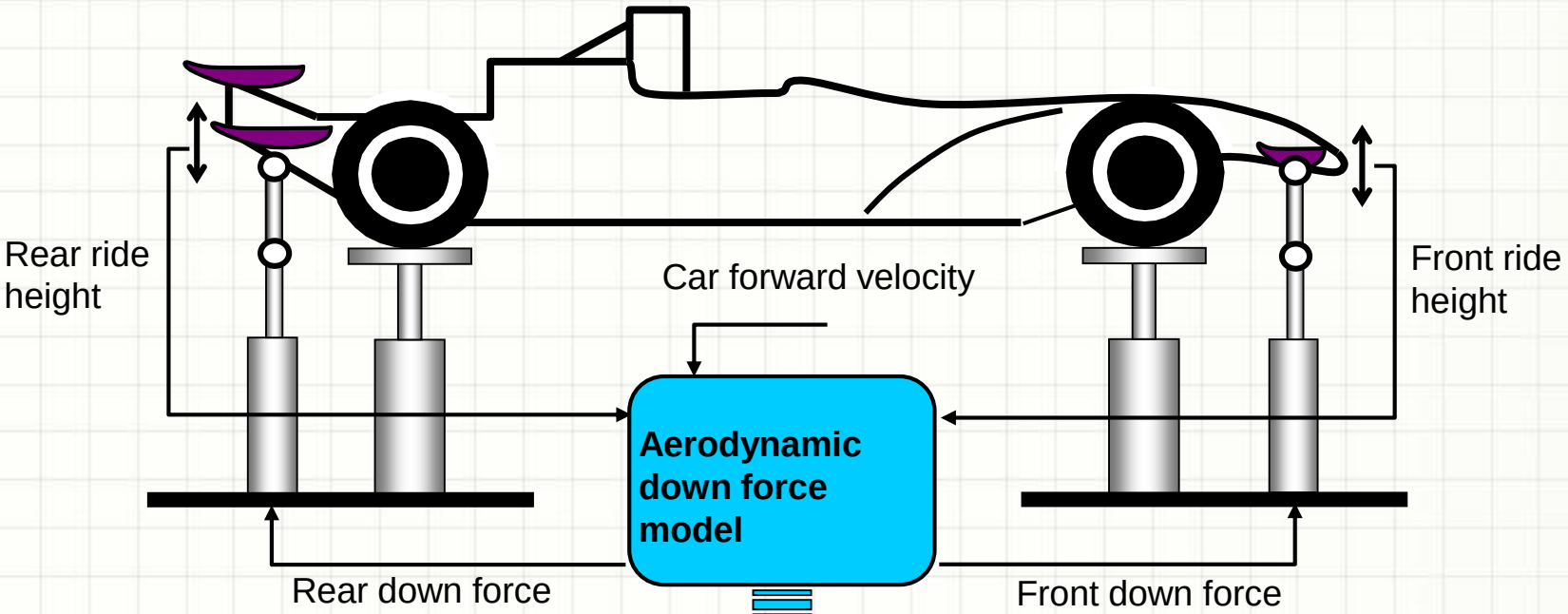
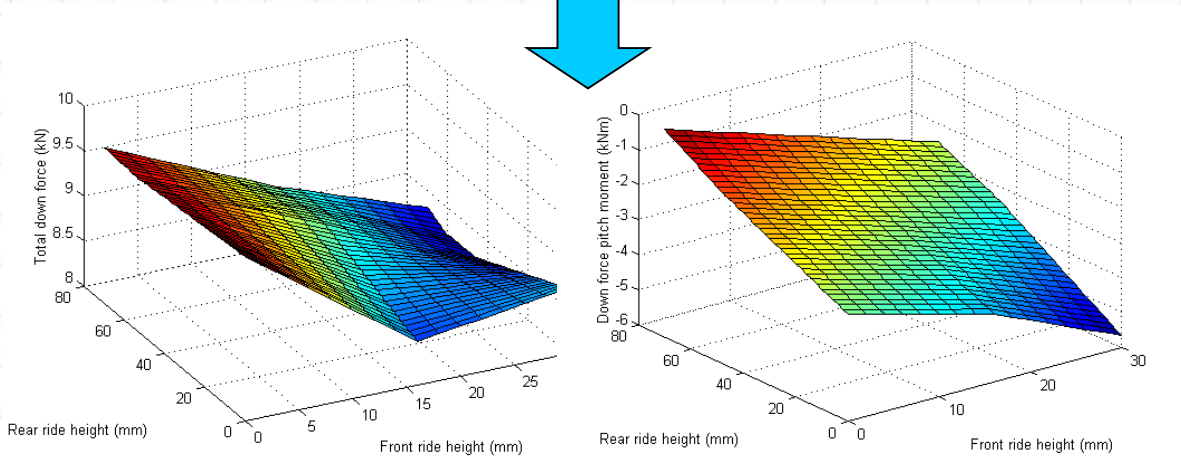
Aerodynamic Model-in-the-Loop





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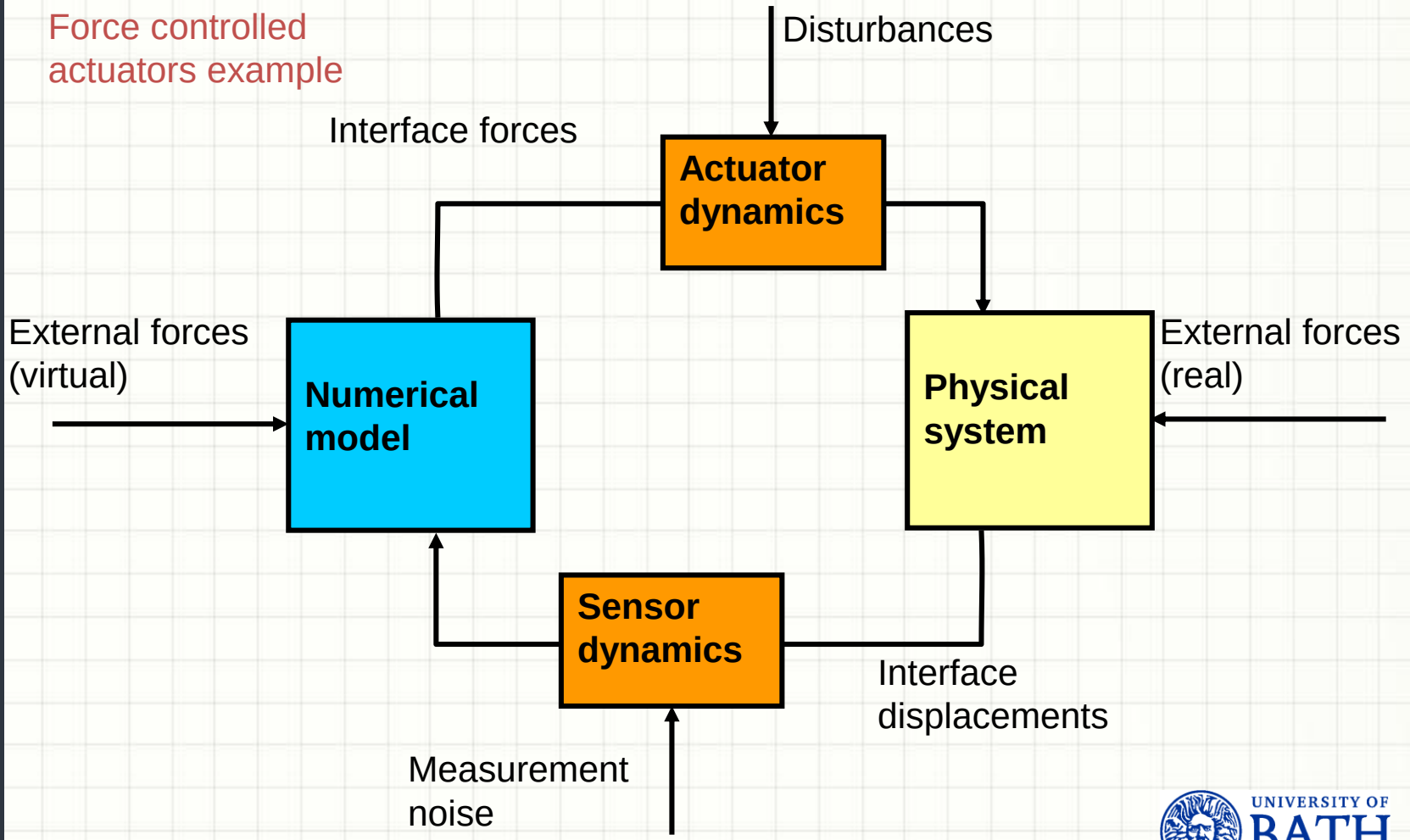
MiL / Hybrid Testing / Substructuring

Force controlled actuators example



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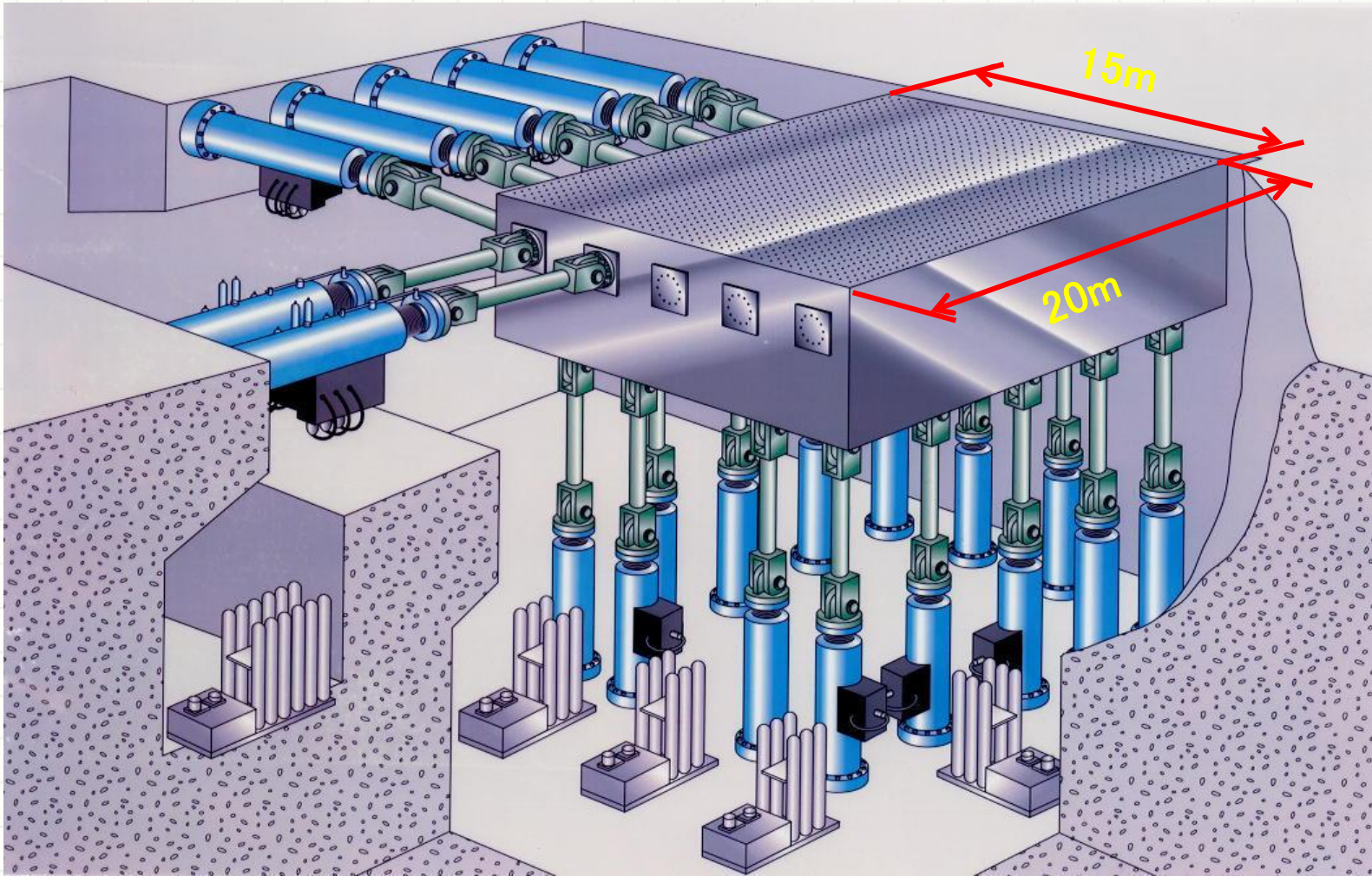
INSTRON

SEISMIC TESTING

Shaking table control



E-defense, Japan

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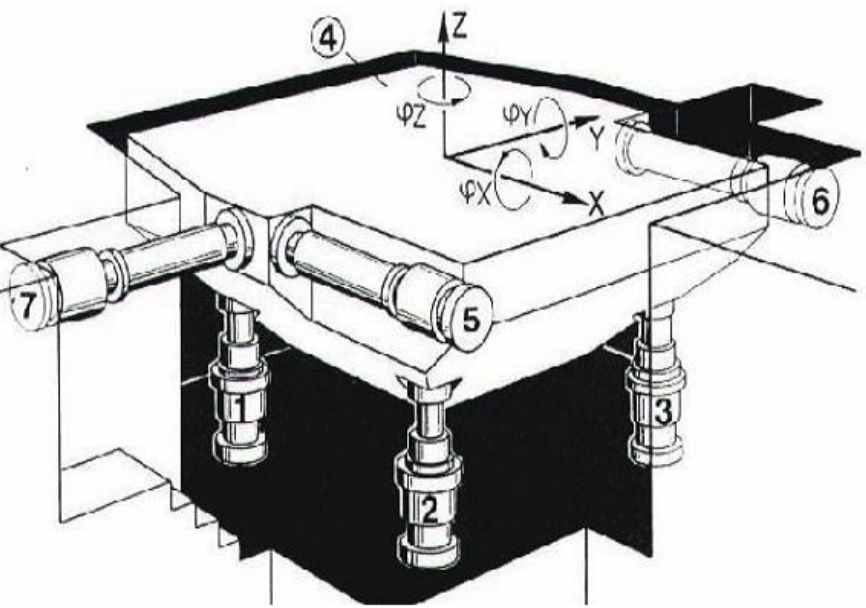

Modal multi-axis inverse model-based closed-loop control

Command Acceleration

Command Position

Washout filter

Low pass filter

+

-

Forward decouple

Mode Inverse

Inverse decouple

$1+\frac{\omega_I}{s}$

Inverse kinematic transform

Valve matching

Valve and actuator

P^{-1}

P

Decoupled axes

Correction for valve pressure drop variation

Forward kinematic transform

$$\left(\frac{s^2}{s^2+2\zeta_w\omega_{nw}s+\omega_w{}^2}\right)\frac{1}{s^2}$$

X 6 axes (X, Y, Z, RX, RY, RZ)

Motion estimator

Position

Acceleration

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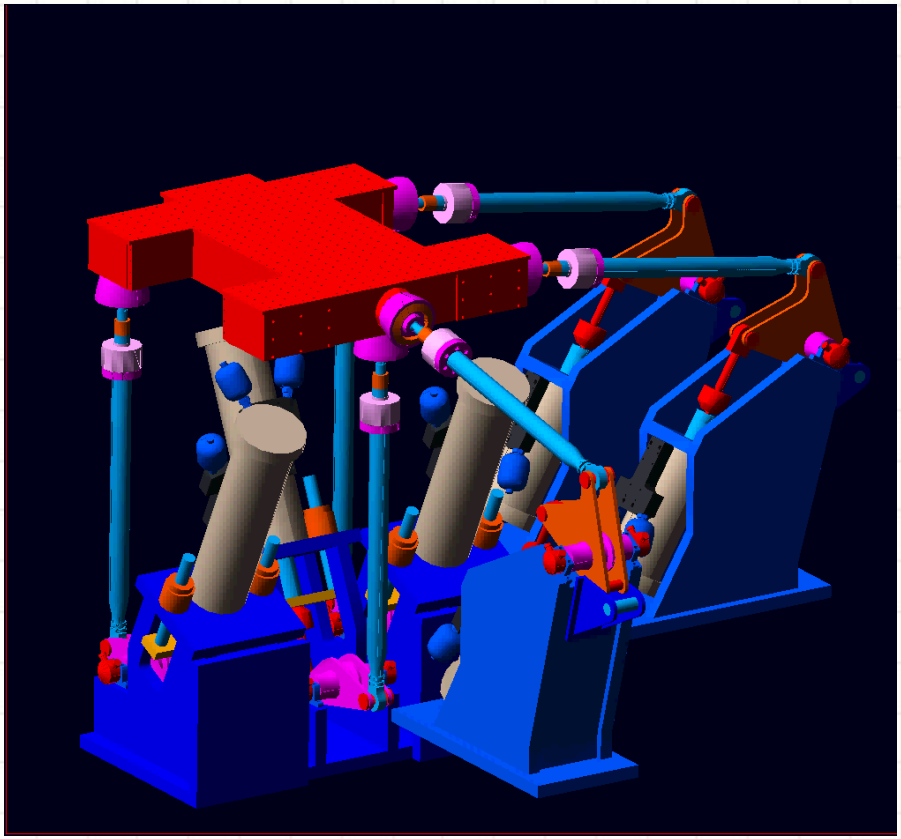
The Role of Modelling and Simulation



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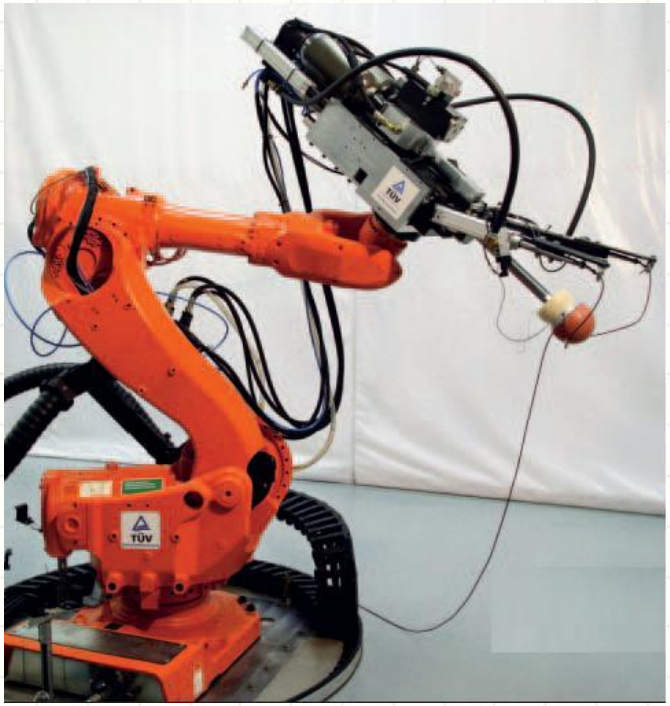
Modelling for closed loop control



Pedestrian impact testing

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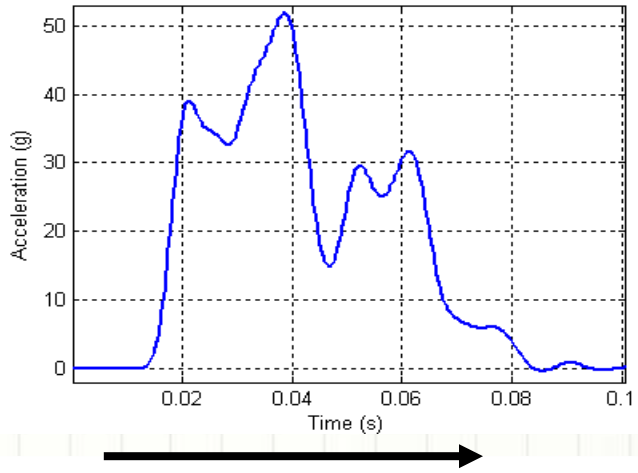
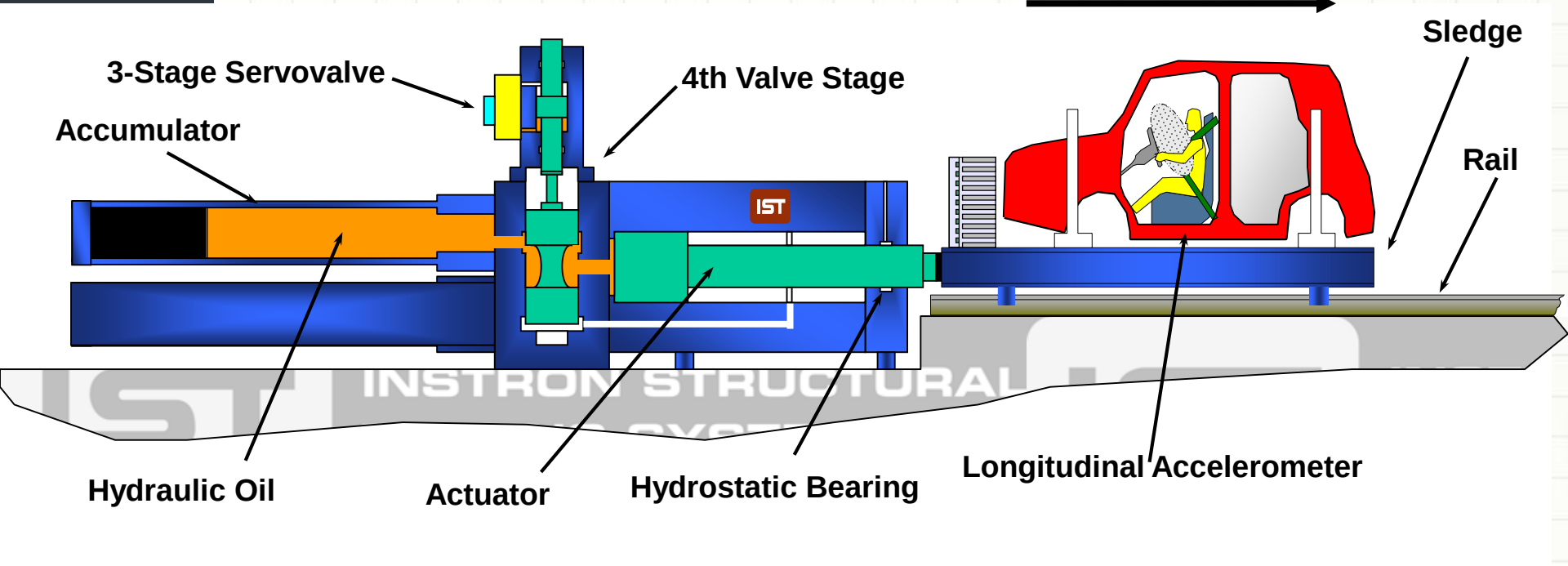
Inverse modelling for iterative control

Hydraulic catapult for occupant restraint testing





Test rig control implementation

Control System

Standard digital controller

Specialised control functions via Simulink Real-Time Code

Virtual systems, e.g. aero model

Valve drives

Sensors

Test rig

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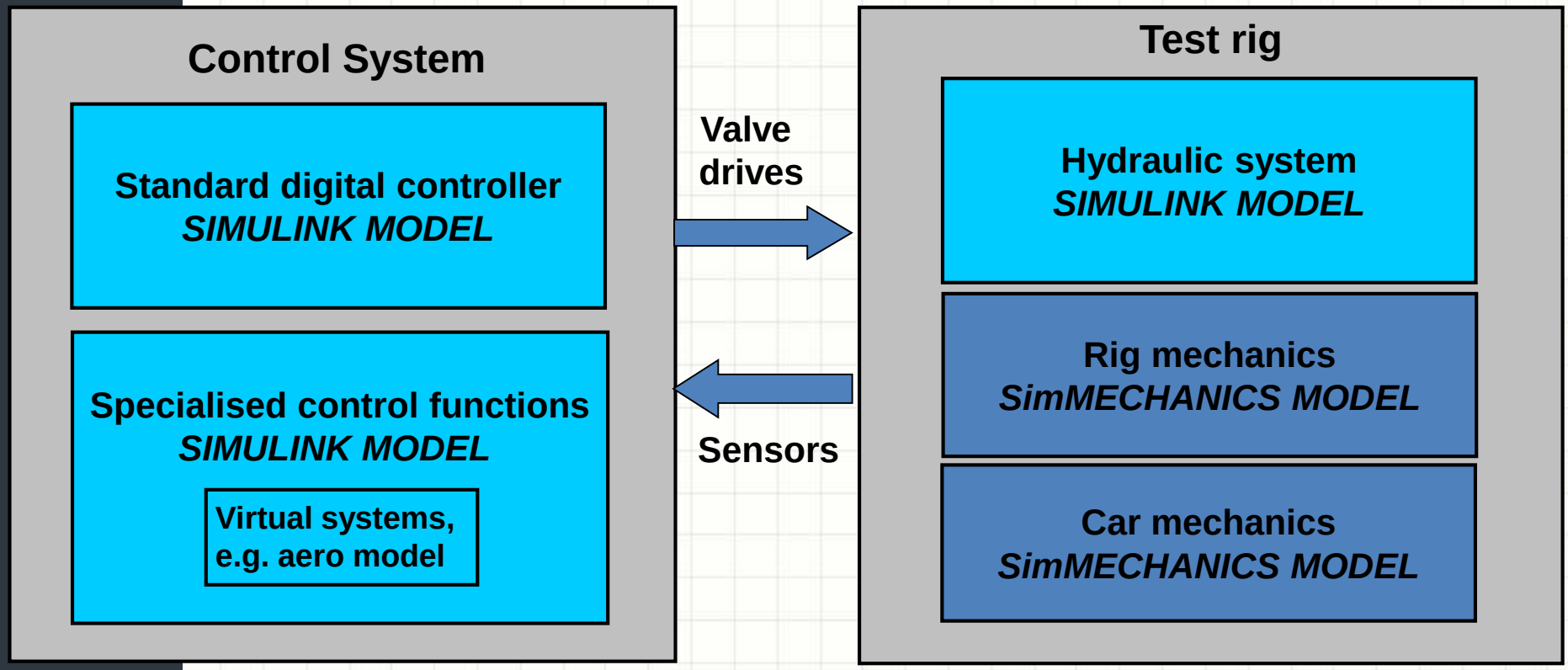
Controller (and rig) development

Off-line and real-time simulation



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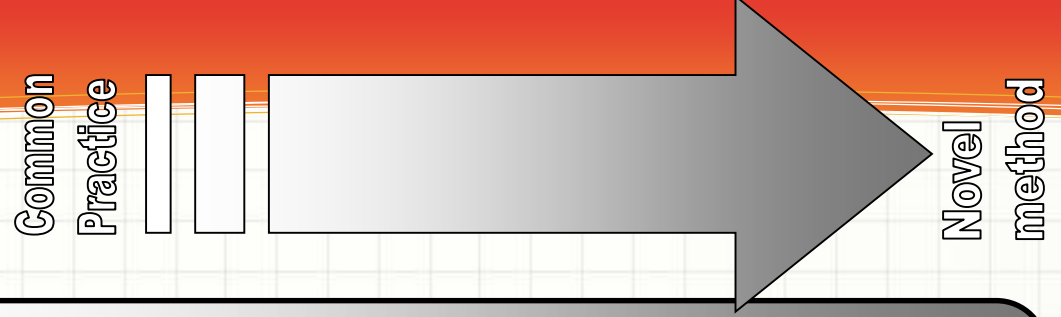
Control algorithms



Closed loop compensation

- PID +First order lag +Notch filter +Pressure f/b +Acceleration f/b
- Three variable control
- H∞ control
- Non-linear model-based control

Command shaping – non-real time

- Iterative control
- Amplitude and phase control
- Repetitive (profile) control

Command shaping – real time

- Command velocity feedforward
- Adaptive inverse control
- 'Delay compensation'

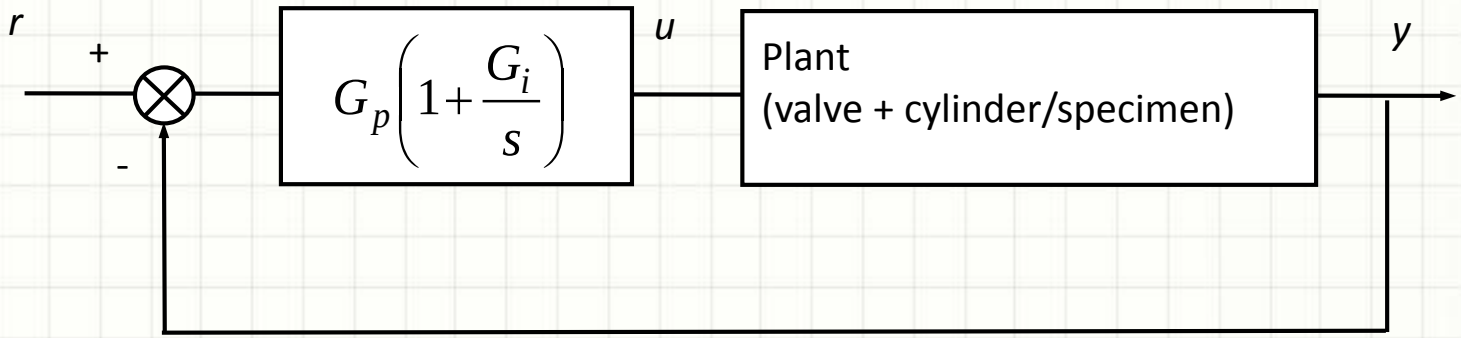
Adaptive control

- Self-tuning and adaptive PID
- Minimal control synthesis

Multi-axis closed-loop control (decoupling)

- Valve cross-compensation
- Co-ordinate transformation
- Specimen motion feedforward
- True modal control

Proportional + Integral (PI) controller



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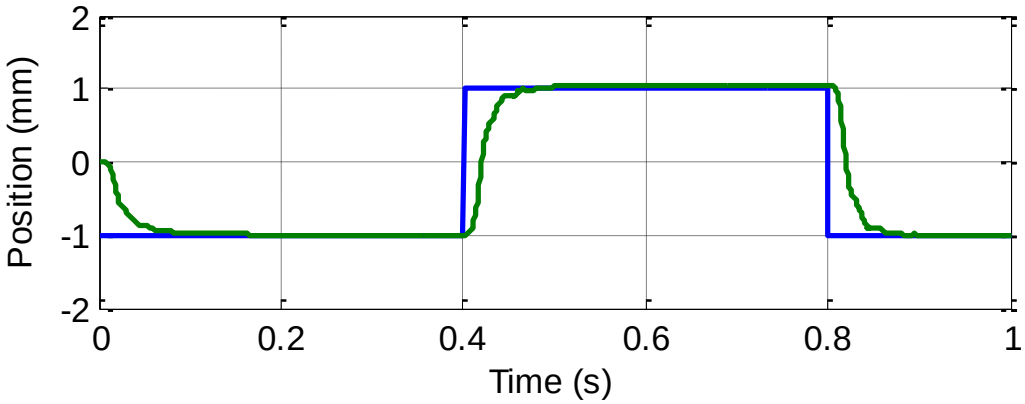
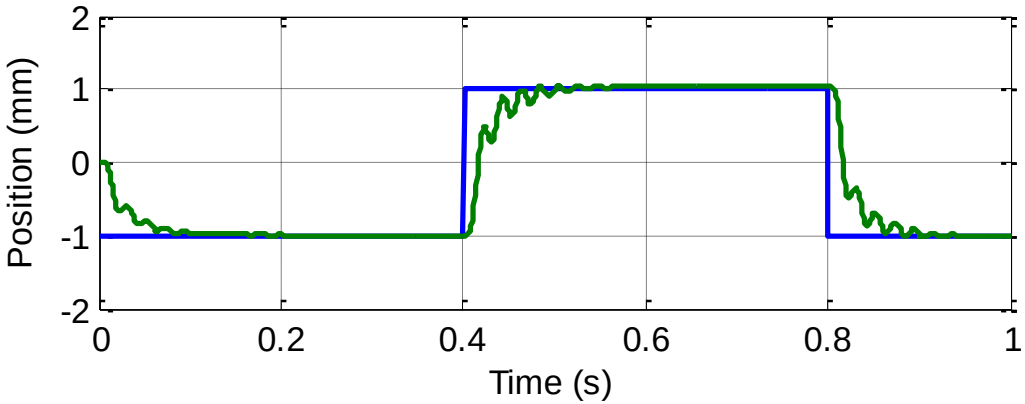
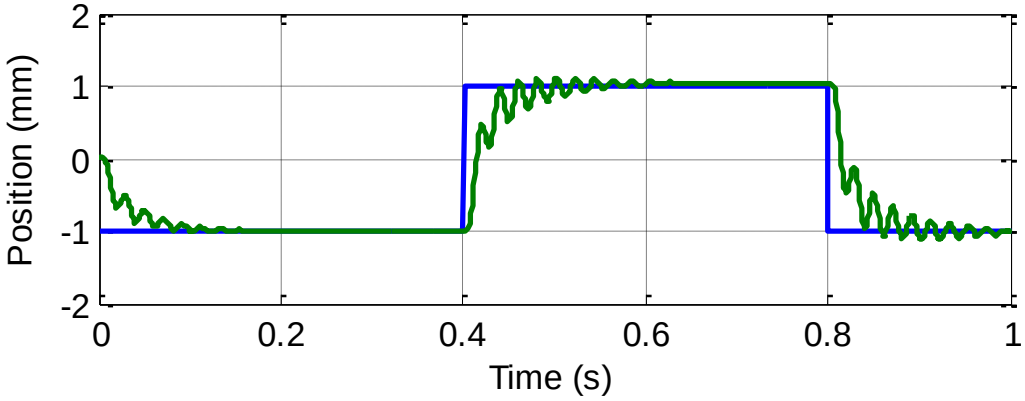
Hydraulic resonance

50Hz hydraulic resonance

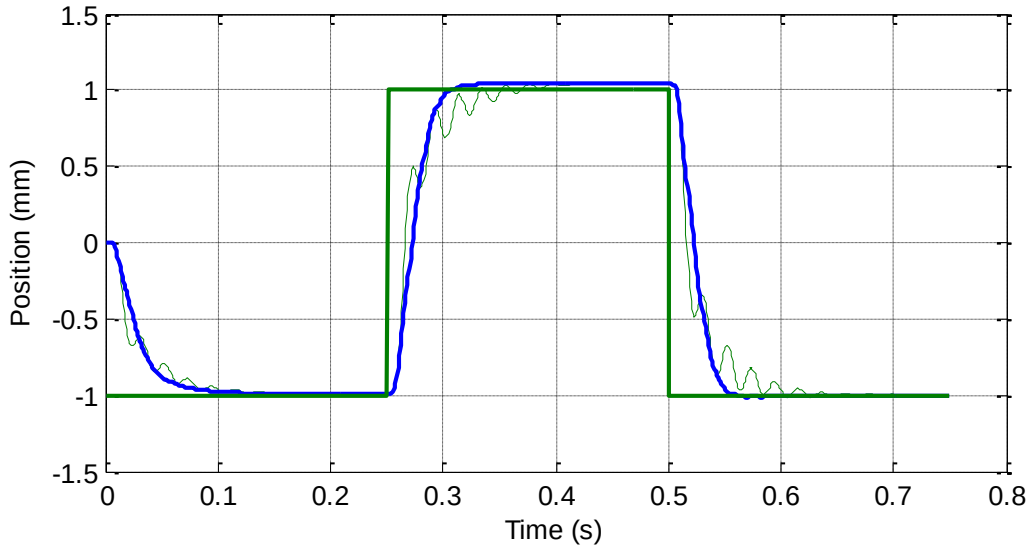
Valve bandwidths:
- 50Hz
- 100Hz
- 200Hz







Resonance compensation



1. acceleration feedback
2. differential pressure or load feedback
3. a first order lag
4. a notch filter
5. A cross-port bleed

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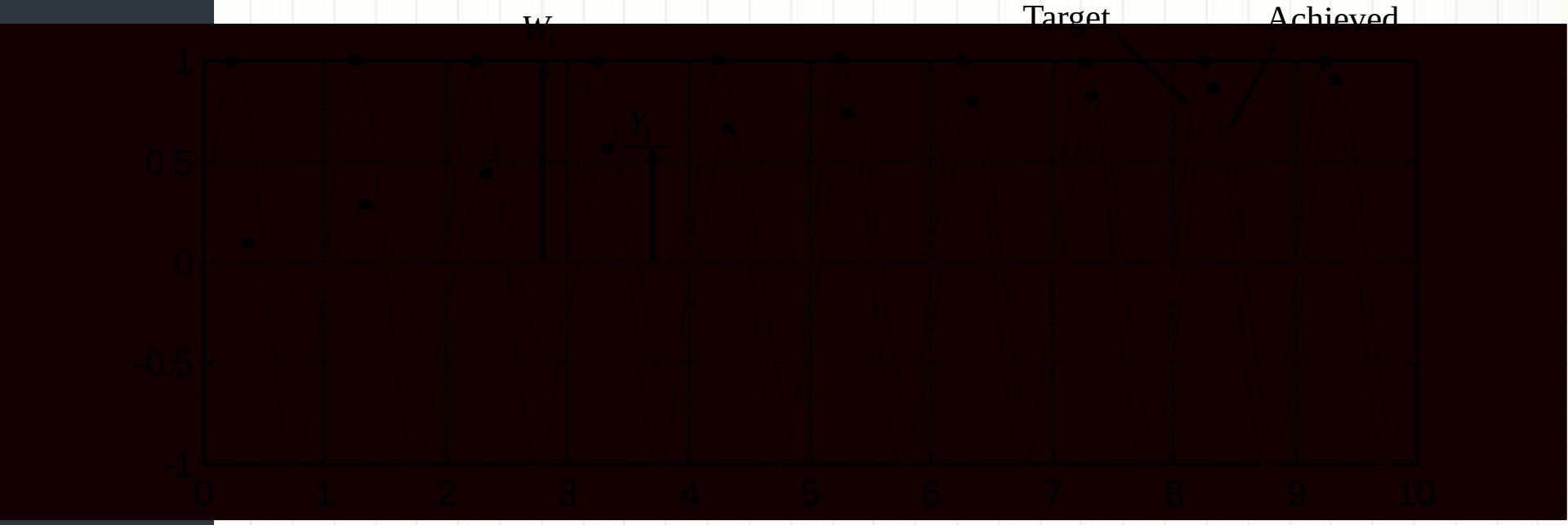
Repetitive control



e.g. Amplitude control

Command adjustment: $R_i = R_{i-1} + \alpha(W_i - Y_i)$

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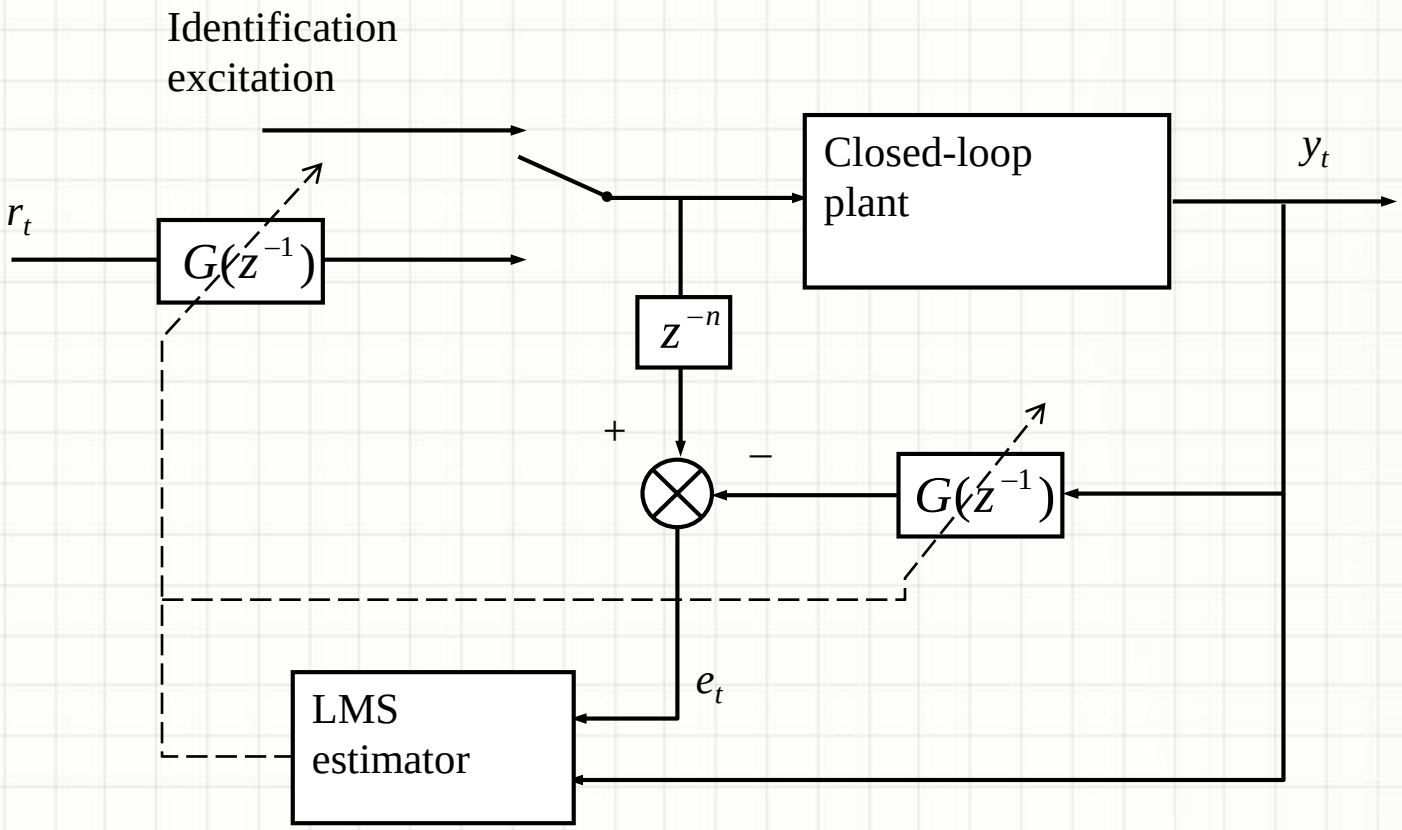
Adaptive & self tuning techniques



Adaptive inverse control

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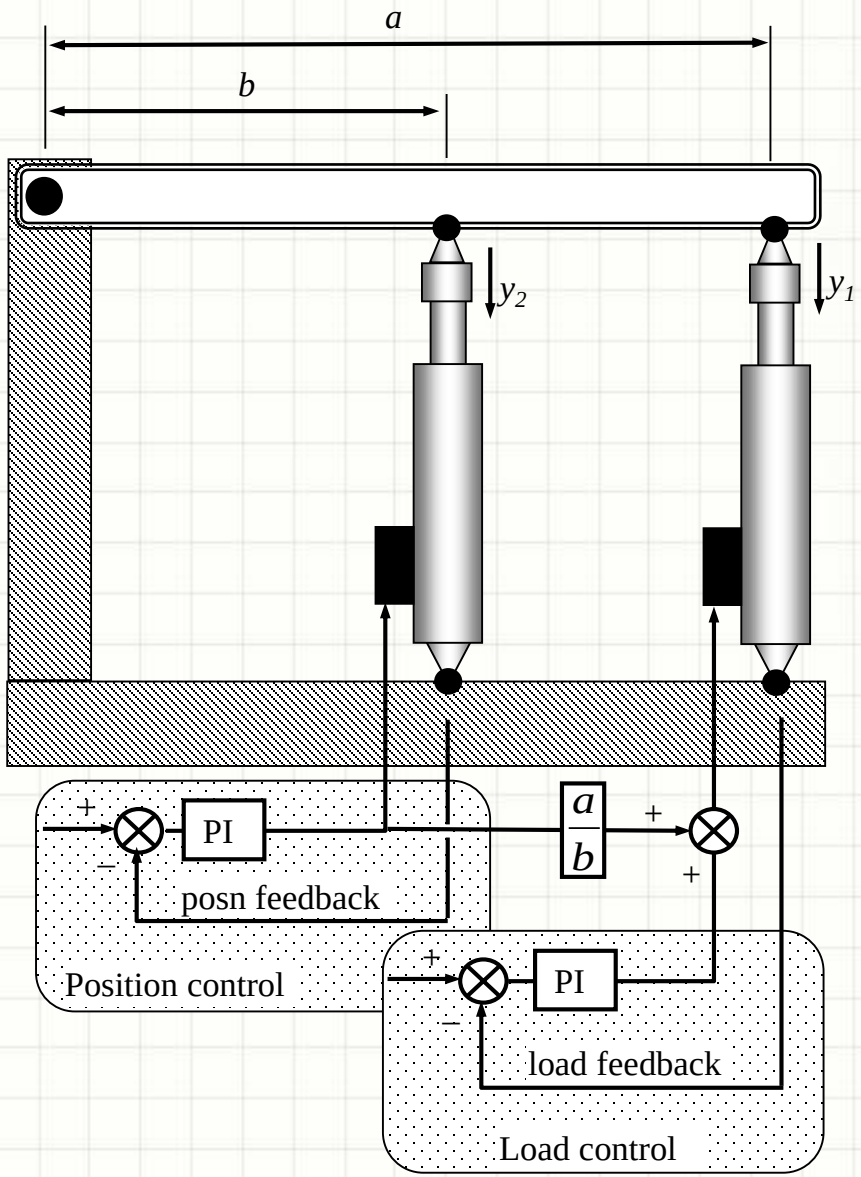
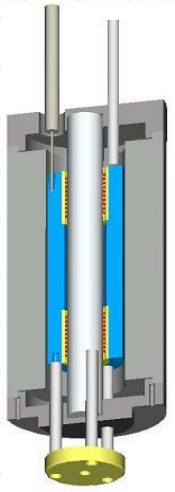
Motion compensated load control

Valve cross-compensation



Technology

- Actuation:
  - servohydraulic good for high force, and bandwidth
  - direct drive (linear) electric motors
  - low friction
- Sensing:
  - Analogue (LVDTs)
  - Digital (ultrasonic, absolute encoders)
  - Load cells – inertial compensation
- Mechanical hardware
  - Frame/joint stiffness
  - Joint friction
  - Structural resonance



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Summary

- Creating high quality rigs for accurate dynamic testing in the laboratory, replicating real-world loads and motions, requires:
  - Specialist design knowledge
  - High quality components
  - System understanding
  - Subtle control algorithms and careful control implementation (e.g. signal conditioning)
- Improvements aided by model-based design and control.
- Hybrid testing is a future direction

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